WELCOME TO
NASA APPLIED REMOTE SENSING TRAINING (ARSET)
WEBINAR SERIES

Water Resources Management Using NASA Earth Science Data

COURSE DATES: EVERY Tuesday, October 13, 20, 27; November 3, 10
TIME: 10 TO 11 AM AND 2 TO 3 PM Eastern US Time
(UTC-4 Hours for October and UTC-5 Hours for November)
Webinar Outline

Week 1
NASA Remote Sensing Data and Applications for Water Resources Management

Week 2
Precipitation and Soil Moisture Data Access and Applications

Week 3
Run off, Streamflow and Reservoir Level Data Access and Applications

Week 4
Evapotranspiration and Ground Water Data Access and Applications

Week 5
Land Data Assimilation for Water Budget Estimation and Case Studies with GIS Applications
Training Team

Instructors:

- Amita Mehta (ARSET): amita.v.mehta@nasa.gov
- Cynthia Schmidt (ARSET): cynthia.l.schmidt@nasa.gov (Week-4)
- Brock Blevins (ARSET): bblevins37@gmail.com

Guest Speakers:

- Eni Njoku (NASA-JPL): eni.g.njoku@jpl.nasa.gov (Week-2)
- Brian Thomas (NASA-JPL): Brian.F.Thomas@jpl.nasa.gov (Week-4)
- Sujay Kumar (NASA-GSFC): sujay.v.kumar@nasa.gov (Week-5)

Spanish Translation:

- David Barbato (ARSET): barbato1@umbc.edu

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- Ana Prados (ARSET) aprados@umbc.edu
Access to ARSET Trainings

http://arset.gsfc.nasa.gov

Webinars

Water Resources Management Using NASA Earth Science Data

Tuesday, October 13, 2015 to Tuesday, November 10, 2015

10 to 11 AM and 2 to 3 PM Eastern US time (UTC-5)

Application Area: Water Resources

Keywords: Flooding, Satellite Imagery, Tools

Instruments/Missions: Aqua, GPM, SMAP, Terra, TRMM

Satellite Remote Sensing of Particulate Matter Air Quality: Data, Tools, Methods and Applications (Aka AOD-PM)

Thursday, October 1, 2015 to Thursday, October 29, 2015

11:30 AM (EDT)

Application Area: Air quality

Keywords: Aerosols, Air Pollution, PM10, PM2.5

Instruments/Missions: MISR, MODIS, VIIRS
Review of Week-1
NASA Satellites and Models for Water Resources Monitoring

Models

GLDAS: Global Land Data Assimilation System

NLDAS: North American Land Data Assimilation System

Landsat (07/1972-present)
TRMM (11/1997-04/2015)
GPM (2/27/2014-present)
Terra (12/1999-present)
Aqua (5/2002-present)
SMAP (1/31/2015-present)
GRACE (3/2002-present)
Jason-1&2 (12/2001-present)

TRMM: Tropical Rainfall Measuring Mission
GRACE: Gravity Recovery and Climate Experiment
GPM: Global Precipitation Measurements
SMAP: Soil Moisture Active Passive
NASA Satellites and Earth Systems Models
Provide global scale water cycle quantities on hourly, daily, seasonal, and multi-year time scales useful for water resources management

- Rain
- Temperature
- Humidity
- Winds
- Soil Moisture
- Snow/Ice
- Clouds
- Terrain
- Ground Water
- Vegetation Index
- Evapotranspiration
- Runoff

**Water Resources Management:**
- Rain Amount, Snowmelt Amount
- Runoff
- Soil Moisture
- Evapotranspiration
- Ground Water

**Hydrology Modeling Inputs:**
- Rain Amount, Snowmelt Amount
- Surface Temperature, Wind, Humidity
- Terrain, Land Cover
- Solar and Terrestrial Radiation at the Surface

All other quantities are available from satellite observations as well as from models. Quantities in green are derived from satellite observations. Quantities in red are from atmosphere-land models in which satellite observations are assimilated.
Agenda for Week-2

Overview of Precipitation and Soil Moisture Data

- Precipitation Data Products from GPM and TRMM
- Snow Cover Data from Terra and Aqua MODIS
- Overview of Soil Moisture Data from SMAP
Precipitation Data Products from GPM and TRMM

For detailed information about GPM please review the following ARSET webinar
## NASA Remote Sensing Data for Rain and Snow

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Sensors</th>
<th>Quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPM 2/2014-Present</td>
<td>Dual Frequency Precipitation Radar (DPR)  \GPM Microwave Imager (GMI)</td>
<td>Rain Rate, Vertical Rain Rate Profile, Accumulated Rain</td>
</tr>
<tr>
<td>TRMM 11/1997-4/2015</td>
<td>Precipitation Radar (PR)  \TRMM Microwave Imager (TMI)  \Visible Infrared Scanner (VIRS)</td>
<td>Rain Rate, Vertical Rain Rate Profile, Accumulated Rain</td>
</tr>
<tr>
<td>Terra and Aqua 12/1999-Present 5/2002-Present</td>
<td>MODerate Resolution Imaging Spectroradiometer (MODIS)</td>
<td>Snow Cover, Vegetation Index, Leaf Area Index, Land Cover</td>
</tr>
</tbody>
</table>

Rain Rate is measured in mm/hour
Accumulated Rain is measured in mm (over a day or a month)
Snow Cover is the fractional area covered by snow
GPM
Global Precipitation Measurement Mission

http://pmm.nasa.gov/GPM

- An international network of satellites with a GPM Core satellite designed to provide global observations of rain and snow
- Initiated by NASA and the JAXA as a successor to TRMM

GPM Core satellite was launched on
February 27th, 2014
GPM Orbits and Spatial Coverage

- GPM is in non-polar, low inclination orbit with 16 orbits per day

- GPM observes global regions between 65° S to 65°N latitudes

- TRMM was in non-polar, low inclination orbit with 16 orbits per day **but provides observation** between 35° S to 35°N latitudes

GPM measurements span middle and high latitudes

The area covered by three TRMM orbits [yellow] versus orbits of the GPM Core Observatory [blue]
# TRMM and GPM Measurements

[http://pmm.nasa.gov/](http://pmm.nasa.gov/)

## TRMM Microwave Imager (TMI)
(Passive Sensor)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequencies</td>
<td>10.7, 19.4, 21.3, 37, 85.5 GH</td>
</tr>
<tr>
<td>Swath</td>
<td>760 km (870* km)</td>
</tr>
<tr>
<td>Resolution</td>
<td>5 to 45 km (channel-dependent)</td>
</tr>
</tbody>
</table>

## Precipitation Radar (PR)
(Active Sensor)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequencies</td>
<td>13.6 GHz (Ku band)</td>
</tr>
<tr>
<td>Swath</td>
<td>220 km (247* km)</td>
</tr>
<tr>
<td>Resolution</td>
<td>5 km</td>
</tr>
</tbody>
</table>

## GPM Microwave Imager (GMI)
(Passive Sensor)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequencies</td>
<td>10.6, 18.7, 23.8, 36.5, 89, 166 &amp; 183 GHz</td>
</tr>
<tr>
<td>Swath width</td>
<td>885 km</td>
</tr>
<tr>
<td>Resolution</td>
<td>~4 to 32 km (channel-dependent)</td>
</tr>
</tbody>
</table>

## Dual-frequency Precipitation Radar (DPR)
(Active Sensor)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequencies</td>
<td>13.6 GHz (Ku), 35.5 Gz (Ka)</td>
</tr>
<tr>
<td>Swath</td>
<td>245 km, 120 km</td>
</tr>
<tr>
<td>Resolution</td>
<td>5.2 km</td>
</tr>
</tbody>
</table>
TRMM and GPM Measurements

http://pmm.nasa.gov/

Compared to TRMM, GPM has:

- Higher sensitivity to light rain and snow
- Better accuracy of measurements
- Improved light rain and snow detection
- Extended Spatial Coverage

- TRMM measurements provide long-term precipitation that is very useful for monitoring climate variability and trends

- TRMM and GPM data will be inter-calibrated to provide a combined, long-term, record in the near future
TMPA: TRMM Multi-satellite Precipitation Analysis
IMERG: Integrated Multi-satellitE Retrievals for GPM

IMERG and TMPA are produced by combining GMI/DPR and TMI/PR data with global constellation of satellites to yield improved spatial/temporal precipitation estimates:

<table>
<thead>
<tr>
<th></th>
<th>IMERG</th>
<th>TMPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal Resolution :</td>
<td>30-minutes</td>
<td>3 hours</td>
</tr>
<tr>
<td>Spatial Resolution:</td>
<td>0.1°x0.1°</td>
<td>0.25°x0.25°</td>
</tr>
<tr>
<td>Spatial Coverage:</td>
<td>Global</td>
<td>Global</td>
</tr>
<tr>
<td></td>
<td>60°S to 60°N</td>
<td>50°S to 50°N</td>
</tr>
</tbody>
</table>

TMPA, available from 1998-present, is widely used in water resources applications and IMERG with improved spatial resolution and coverage will replace TMPA in many applications.
GPM IMERG Data Products

2. IMERG Data Sets

Multiple runs accommodate different user requirements for latency and accuracy

- "Early" – 4 hours (flash flooding)
- "Late" – 12 hours (crop forecasting)
- "Final" – 3 months (research data)

Time intervals are half-hourly and monthly (Final only)

0.1° global CED grid

- PPS will provide subsetting by parameter and location
- Initial release covers 60°N-S

User-oriented services

- Interactive analysis (GIOVANNI)
- Alternate formats (KMZ, KML, TIFF, WRF files, …)
- Area averages

<table>
<thead>
<tr>
<th>Half-hourly data file (Early, Late, Final)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. [multi-sat.] precipitationCal</td>
</tr>
<tr>
<td>2. [multi-sat.] precipitationUncal</td>
</tr>
<tr>
<td>3. [multi-sat. precip] randomError</td>
</tr>
<tr>
<td>4. [PMW] HQprecipitation</td>
</tr>
<tr>
<td>5. [PMW] HQprecipSource [identifier]</td>
</tr>
<tr>
<td>6. [PMW] HQobservationTime</td>
</tr>
<tr>
<td>7. IRprecipitation</td>
</tr>
<tr>
<td>8. IRkalmanFilterWeight</td>
</tr>
<tr>
<td>9. probabilityLiquidPrecipitation [phase]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Monthly data file (Final)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. [sat.-gauge] precipitation</td>
</tr>
<tr>
<td>2. [sat.-gauge precip] randomError</td>
</tr>
<tr>
<td>3. GaugeRelativeWeighting</td>
</tr>
<tr>
<td>4. probabilityLiquidPrecipitation [phase]</td>
</tr>
</tbody>
</table>

Courtesy: George Huffman (NASA-GSFC)

PPS: Precipitation Processing System
CED: Cylindrical Equidistant
## GPM and TRMM Data Access Tools

<table>
<thead>
<tr>
<th>Tools</th>
<th>Data Products and Formats</th>
<th>Analysis and/or Visualization</th>
<th>Data Download</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirador <a href="http://mirador.gsfc.nasa.gov">http://mirador.gsfc.nasa.gov</a></td>
<td>L1B, L2, and L3 from TMI and GMI, PR and DPR Data, Combined TMI-PR and GMI-DPR&lt;br&gt; TMPA 3-hourly, Monthly&lt;br&gt; IMERG Half-hourly, Monthly&lt;br&gt; Orbital and Gridded Daily, Monthly&lt;br&gt; HDF5, OPenDAP (can be converted to ASCII, Binary, NetCDF)</td>
<td>N/A</td>
<td>Batch Download</td>
</tr>
<tr>
<td>Giovanni <a href="http://giovanni.gsfc.nasa.gov/giovanni/">http://giovanni.gsfc.nasa.gov/giovanni/</a></td>
<td>TMPA (3B42) 3-hourly, (3B43) Monthly&lt;br&gt; IMERG Half-hourly, Monthly&lt;br&gt; NetCDF, GeoTIFF, PNG</td>
<td><strong>Visualization:</strong> Map, Time Series, Scatter Plot Histogram&lt;br&gt; <strong>Analysis:</strong> Time-averaged Maps, Time Series, Scatter Plot, Map Correlations, Vertical Profiles, Time-averaged Differences</td>
<td>Download by Select and Click on Data Files</td>
</tr>
<tr>
<td>PPS/STORM <a href="https://storm.pps.eosdis.nasa.gov/storm">https://storm.pps.eosdis.nasa.gov/storm</a></td>
<td>L1B and 1C, L2, L3 TMI, PR, GMI, DPR&lt;br&gt; TMI-PR and GMI-DPR Combined Data&lt;br&gt; Orbital and Gridded Daily, Monthly&lt;br&gt; TMPA 3-hourly, Monthly and IMERG Half-hourly, Monthly&lt;br&gt; HDF5, PNG</td>
<td>Map Visualization, Interactive Latitude/Longitude Point Data Value Display</td>
<td>FTP</td>
</tr>
</tbody>
</table>
Mirador: Data Search and Access

http://mirador.gsfc.nasa.gov/

- Search Data using Keyword
- Spatial Selection by latitude-longitude
- Temporal Selection
- Spatial Selection from Map
- Bulk data download by using scripts
Mirador: Data Search and Access

http://mirador.gsfc.nasa.gov/

IMERG Half-hourly Data Files List

Download each file by clicking on HDF5 or OPeNDAP OR Select Multiple files and add to cart

Select File(s) by checking the box
Mirador: Data Search and Access

http://mirador.gsfc.nasa.gov/

Data Checkout

Download Data by using these scripts
Giovanni Version 4

http://giovanni.gsfc.nasa.gov/giovanni/

Analysis/Plot Options
Temporal and Spatial Search
Map and Shapefile Selection for various countries or US States
Search data by keyword
Plot Data
Giovanni Version 4

http://giovanni.gsfc.nasa.gov/giovanni/

Search GPM data and Select Spatial, Temporal, Plot Options

July, 2014 Monthly IMERG over the US
Giovanni Version 4

http://giovanni.gsfc.nasa.gov/giovanni/

Search and Plot Result: IMERG Rain Rate for July 2014 over the US
Precipitation Processing System (PPS)
Science Team On-Line Request Module (STORM)

https://storm-pps.gsfc.nasa.gov/storm/

STORM is specifically designed for GPM and TRMM Precipitation data search, selection, download, and visualization
Precipitation Processing System (PPS) Science Team On-Line Request Module (STORM)

https://storm-pps.gsfc.nasa.gov/storm/

STORM is specifically designed for GPM and TRMM Precipitation data search, selection, download, and visualization.

Requires User Registration

Data Product Search
Precipitation Processing System (PPS)
Science Team On-Line Request Module (STORM)
https://storm-pps.gsfc.nasa.gov/storm/

Product Selection, Download, and Visualization by using Tool for High-resolution Observation Review (THOR)

Precipitation on November 15, 2014
Ground Validation and Field Data Information

http://pmm.nasa.gov/science/ground-validation
Snow Data Products
## Review of Terra and Aqua


### Terra
- Polar, Sun-Synchronous Orbit, Global Coverage
- Twice-daily Observations 10:30 AM/PM Descending Orbits
- From 12/1999 – Present

### Aqua
- Polar, Sun-Synchronous Orbit, Global Coverage
- Twice-daily Observations 1:30 AM/PM Descending Orbits
- From 5/2002 – Present
Terra and Aqua
MODerate Resolution ImagingSpectroradiometer (MODIS)
http://modis.gsfc.nasa.gov/

- A key instrument aboard Terra and Aqua providing 4-times per day observations (1:30 and 10:30 AM/PM) from the two satellites
- 36 spectral bands ranging from 0.41 to 14.385 microns
- Many applications, including snow/ice, clouds, vegetation, aerosol
- Available in various resolution (depends on product)

http://modis-snow-ice.gsfc.nasa.gov/
There are Two MODIS-based Snow Data Products

- Standard MODIS Product: Fractional Snow Cover
- MODSCAG (MODIS Snow Covered Area and Grain-size) Product: Fractional Snow Cover, Grain Size, Snow Water Equivalent
MODIS Standard Products: Daily, 8-Day, Monthly Snow Cover available from Terra and Aqua

<table>
<thead>
<tr>
<th>Long Name</th>
<th>Earth Science Data Type (ESDT)</th>
<th>Spatial Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODIS/Terra Snow Cover 5-Min L2 Swath 500m</td>
<td>MOD10_L2</td>
<td>500-m resolution, swath of MODIS data</td>
</tr>
<tr>
<td>MODIS/Terra Snow Cover Daily L3 Global 500m SIN Grid (includes daily snow albedo)</td>
<td>MOD10A1</td>
<td>500-m resolution, projected, gridded tile data</td>
</tr>
<tr>
<td>MODIS/Terra Snow Cover 8-Day L3 Global 500m SIN Grid</td>
<td>MOD10A2</td>
<td>500-m resolution, projected, gridded tile data</td>
</tr>
<tr>
<td>MODIS/Terra Snow Cover Daily L3 Global 0.05Deg CMG</td>
<td>MOD10C1</td>
<td>0.05° resolution, lat/lon climate modeling grid</td>
</tr>
<tr>
<td>MODIS/Terra Snow Cover 8-Day L3 Global 0.05Deg CMG</td>
<td>MOD10C2</td>
<td>0.05° resolution, lat/lon climate modeling grid</td>
</tr>
<tr>
<td>MODIS/Terra Snow Cover Daily L3 Global 0.25Deg CMG</td>
<td>Not yet a standard product</td>
<td>0.25° resolution, lat/lon climate modeling grid</td>
</tr>
<tr>
<td>MODIS/Terra Snow Cover Monthly L3 Global 0.05Deg CMG</td>
<td>MOD10CM</td>
<td>0.05° resolution, lat/lon climate modeling grid</td>
</tr>
<tr>
<td>MODIS/Aqua Snow Cover 5-Min L2 Swath 500m</td>
<td>MYD10_L2</td>
<td>500-m resolution, swath of MODIS data</td>
</tr>
<tr>
<td>MODIS/Aqua Snow Cover Daily L3 Global 500m SIN Grid (includes daily snow albedo)</td>
<td>MYD10A1</td>
<td>500-m resolution, projected, gridded tile data</td>
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<td>MODIS/Aqua Snow Cover 8-Day L3 Global 500m SIN Grid</td>
<td>MYD10A2</td>
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<td>MODIS/Aqua Snow Cover Daily L3 Global 0.05Deg CMG</td>
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<tr>
<td>MODIS/Aqua Snow Cover 8-Day L3 Global 0.05Deg CMG</td>
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<td>0.05° resolution, lat/lon climate modeling grid</td>
</tr>
<tr>
<td>MODIS/Aqua Snow Cover Monthly L3 Global 0.05Deg CMG</td>
<td>MYD10CM</td>
<td>0.05° resolution, lat/lon climate modeling grid</td>
</tr>
</tbody>
</table>
MODIS Snow Products are available from the National Snow and Ice Data Center  http://nsidc.org/

MODIS monthly snow cover can be visualized on Google Earth maps from  http://nsidc.org/data/virtual_globes/index.html

Data Start Date: 2000-02-24
Daily, 8-Day, Monthly
Coverage: Global
Multiple Spatial Resolutions
Selected Aqua-MODIS Snow Product from Reverb/ECHO

http://reverb.echo.nasa.gov/reverb

Swath, Daily, and Monthly products are available
Near-real Time Standard MODIS Products

http://lance-modis.eosdis.nasa.gov/

LANCE-MODIS will operate on a 7x24 hour basis. LANCE-MODIS has two standalone systems that use different network routes. It is expected that this redundancy will reduce the system downtime to less than 1%.

Whereas the standard MODIS forward processing acquires 2-hour L0 files for Aqua and Terra from EDOS within 7-8 hours of real time, LANCE-MODIS acquires session-based L0 files from EDOS and the end of the session is available within 10-30 minutes after real time. LANCE-MODIS uses the Terra attitude and ephemeris data entrained in the L0 data. However, for Aqua the attitude and ephemeris data are acquired from the EDOS rate buffer. All of the MODIS Level 1 (L1), L2 and L3 products generated by LANCE-MODIS have been modified to add "NRT" metadata to the filenames to enable the products to be distinguished from the MODIS standard forward-processed products. LANCE-MODIS acquires all of the ancillary products from the data suppliers. The production rules for some of the science codes have been relaxed with respect to these ancillary data to allow the data products to be generated within 3 hours of real time.

Data products are archived in a rolling archive for 7+ days and are available for distribution by direct access to the FTP sites.

LANCE-MODIS Details:

- Hardware Configuration
- Data Flows for MODIS
- Distribution and Latency Metrics
Near-real Time Standard MODIS Products
http://lance-modis.eosdis.nasa.gov/

Level-2 Swath data (500) m and 5 Km resolution Snow Cover available from Terra and Aqua MODIS

<table>
<thead>
<tr>
<th>Terra</th>
<th>Fraction</th>
<th>Browse</th>
<th>MOD10_L2</th>
<th>0.26</th>
<th>L2 Snow Cover, 5-Min Swath 500m</th>
<th>N/A</th>
<th>07</th>
<th>0:46</th>
<th>1:32</th>
<th>3:14</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2 Coarse Snow Cover, 5-Min Swath 5km</td>
<td>MOD10L2C</td>
<td>0.17</td>
<td>L2 Snow</td>
<td>N/A</td>
<td>0.46 (8)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aqua</th>
<th>Fraction</th>
<th>Browse</th>
<th>MYD10_L2</th>
<th>L2 Snow Cover, 5-Min Swath 500m</th>
<th>N/A</th>
<th>07</th>
<th>1:00</th>
<th>1:47 (25)</th>
<th>3:30</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2 Coarse Snow Cover, 5-Min Swath 5km</td>
<td>MYD10L2C</td>
<td>0.17</td>
<td>L2 Snow</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
MODSCAG Snow Products
From: Thomas H. Painter and Chris Mattmann (NASA JPL)
Limitation of MODIS Data: No Snow Mapping Under Clouds

Hindu Kush  April 9/2009

Cloud

MODSCAG
http://snow.jpl.nasa.gov/portal/browse/dataset/urn:snow:MODSCAG
http://snow.jpl.nasa.gov/portal/browse/dataset/urn:snow:MODSCAG

MODSACG Data Access and Mapping
MODSCAG, Snow and Dust Radiative Forcing Information, along with CBRFC Modeling Analysis is used in Decision Making for River Basin management.
Soil Moisture Data
SMAP Data Products and Applications

Eni Njoku
Erika Podest
Vanessa Escobar

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA

Outline

1. Overview and Mission Objectives
2. Instruments (radar and radiometer)
3. Retrieval Algorithms
4. Data Products
5. Applications

Details provided in SMAP Handbook

Credits: SMAP Project Team
SMAP Science Team

Why Soil Moisture?

- Enhanced weather & climate forecasting
- Improved agricultural productivity and crop yield predictions
- Drought monitoring and early warning
- Flood monitoring and prediction
- Human health and vector borne diseases
Why Measure from Space?

SMAP provides a capability for global observations of soil moisture and its frozen or thawed state at high spatial resolution and frequent temporal revisit

- Current ground measurements of soil moisture are sparse and have limited global coverage
- Previous space missions have relatively low soil moisture accuracy, resolution, and coverage
- SMAP provides 10–40 km spatial resolution, 3-day global revisit, accuracy of 0.04 m³/m³

Inter-storm soil moisture dry-down
- Average inter-storm period => 3-day sampling or better is required to resolve soil moisture variability

[Sun et al. (2006): How often does it rain?, J. Climate, 19]
SMAP uses both “Passive” and “Active” Remote Sensing to measure Soil Moisture

Passive Sensors:
The source of radiant energy arises from natural sources... Sun, Earth, other “hot” bodies

Active Sensors:
Provide their own artificial radiant energy source for illumination... RADAR, Synthetic Aperture Radar (SAR), LIDAR
• With optical and infrared wavelength sensors the soil is masked by clouds and vegetation. Also, optical sensors operate by measuring scattered sunlight and are “daytime only”.

• Microwaves can penetrate through clouds and vegetation, operate day and night, and are highly sensitive to the water in the soil due to the change in the soil microwave dielectric properties.
Measurement Approach (3)

Radiometers measure “brightness temperature”, \( T_B \) (K) 
Radars measure “backscatter cross-section”, \( \sigma_0 \) (dB)

Contributions to emission and backscatter include three 
terms: soil, vegetation, and soil-vegetation interaction

Soil moisture is the dominant contributor to the signal

\[ L \text{ is the vegetation attenuation factor, } \exp(-\tau_o/cos\theta) \]

Retrievals invert these equations to obtain soil moisture, with corrections for vegetation, roughness and surface temperature

Experimental data showing brightness temperature sensitivity to soil moisture for bare, smooth soil
SMAP Mission Design

**INSTRUMENT**
- L-band (1.2-GHz) radar (JPL)
- L-band (1.4-GHz) radiometer (GSFC)
- Shared antenna (6-m diameter)
- Conical scan: 13–14.6 rpm; 40° incidence
- Contiguous 1,000-km swath width

**SPACECRAFT (& RADAR ELECTRONICS)**
- JPL developed & built
- JPL's MSAP/MSL avionics, power assys with a small number of new mission-unique card designs
- 951-kg wet mass (Observatory-level)
- 1450-W capacity (Observatory-level)
- 80-kg propellant capacity
- Commercial space electronics elsewhere

**SMAP Flight System (Observatory)**

**Near-Earth Network**

**Surface Validation**

**SCIENCE DATA PRODUCTS**
- Soil Moisture & Freeze/Thaw State Data Products
- Alaska Satellite Facility Data Center (radar L1 products)
- National Snow and Ice Data Center (all other products)

**SMAP Mission Operations & Data Processing**
(JPL, GSFC)

**SMAP Data Products and Applications**

**NASA ARSET Webinar: Water Resources Management, October 20, 2015**

**Launch:**
Delta II 7320-10C
- January 31, 2015
- 6:22 AM pacific
- Vandenberg Air Force Base

**685-km polar orbit (Sun-sync)**
- 8-day repeat ground track
- Continuous instrument operation
- 2- to 3-day global coverage
- 3-year mission duration

**Soil Moisture & Freeze/Thaw State Data Products**
- Alaska Satellite Facility Data Center (radar L1 products)
- National Snow and Ice Data Center (all other products)
SMAP Data Products

- Datasets in **Green Text** are publicly available in “beta” version via the ASF and NSIDC data centers

<table>
<thead>
<tr>
<th>Data Product Short Name</th>
<th>Description</th>
<th>Grid Resolution</th>
<th>Granule Extent</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1A_Radar</td>
<td>Parsed Radar Instrument Telemetry</td>
<td></td>
<td>Half Orbit</td>
</tr>
<tr>
<td>L1A_Radiometer</td>
<td>Parsed Radiometer Instrument Telemetry</td>
<td></td>
<td>Half Orbit</td>
</tr>
<tr>
<td>L1B_S0_LoRes</td>
<td>Low Resolution Radar $\sigma_0$ in Time Order</td>
<td>5x30 km (10 slices)</td>
<td>Half Orbit</td>
</tr>
<tr>
<td>L1C_S0_HiRes</td>
<td>High Resolution Radar $\sigma_0$ on Swath Grid</td>
<td>1 km</td>
<td>Half Orbit</td>
</tr>
<tr>
<td>L1B_TB</td>
<td>Radiometer $T_B$ in Time Order</td>
<td>39x47 km</td>
<td>Half Orbit</td>
</tr>
<tr>
<td>L1C_TB</td>
<td>Radiometer $T_B$</td>
<td>36 km</td>
<td>Half Orbit</td>
</tr>
<tr>
<td>L2_SM_A</td>
<td>Radar Soil Moisture (includes Freeze-Thaw)</td>
<td>3 km</td>
<td>Half Orbit</td>
</tr>
<tr>
<td>L2_SM_P</td>
<td>Radiometer Soil Moisture</td>
<td>36 km</td>
<td>Half Orbit</td>
</tr>
<tr>
<td>L2_SM_AP</td>
<td>Active-Passive Soil Moisture</td>
<td>9 km</td>
<td>Half Orbit</td>
</tr>
<tr>
<td>L3_FT_A</td>
<td>Daily Global Composite Freeze/Thaw State</td>
<td>3 km</td>
<td>North of 45° N</td>
</tr>
<tr>
<td>L3_SM_A</td>
<td>Daily Global Composite Radar Soil Moisture</td>
<td>3 km</td>
<td>Global</td>
</tr>
<tr>
<td>L3_SM_P</td>
<td>Daily Global Composite Radiometer Soil Moisture</td>
<td>36 km</td>
<td>Global</td>
</tr>
<tr>
<td>L3_SM_AP</td>
<td>Daily Global Composite Active-Passive Soil Moisture</td>
<td>9 km</td>
<td>Global</td>
</tr>
<tr>
<td>L4_SM</td>
<td>Surface &amp; Root Zone Soil Moisture</td>
<td>9 km</td>
<td>Global</td>
</tr>
<tr>
<td>L4_C</td>
<td>Carbon Net Ecosystem Exchange</td>
<td>9 km</td>
<td>Global</td>
</tr>
</tbody>
</table>
Planned Data Delivery Schedule

Pre-launch Preparation

Launch January 31, 2015

In-Orbit Checkout (3 months)
Formal start of SMAP Science Mission

Beta release of L1 products and start of routine delivery

L1 validation (6 months)
Delivery of validated L1 products to Data Center

Beta release of L2-L4 products and start of routine delivery

L2-L4 validation (12 months)
Delivery of validated L2-L4 products to Data Center

Pre-launch Preparation

Beta release of L1 products and start of routine delivery

L1 validation (6 months)
Delivery of validated L1 products to Data Center

L2-L4 validation (12 months)
Delivery of validated L2-L4 products to Data Center

January 31, 2015

April 30, 2015
July 31, 2015
October 31, 2015
April 30, 2016
L+3 mo
L+6 mo
L+9 mo
L+15 mo
## Current Status

<table>
<thead>
<tr>
<th>Date</th>
<th>Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 31, 2015</td>
<td>SMAP launch</td>
</tr>
<tr>
<td>February 24</td>
<td>Antenna reflector deployed</td>
</tr>
<tr>
<td>March 26</td>
<td>Antenna spin-up to 14.6 RPM</td>
</tr>
<tr>
<td>March 31</td>
<td>Radiometer begins routine science operation</td>
</tr>
<tr>
<td>April 13</td>
<td>Radar begins routine science operation</td>
</tr>
</tbody>
</table>
| July 7                | **Radar stops transmitting (traced to low-voltage power supply of radar amplifier)**<sup>1</sup>  
                         |   **Radiometer continues to operate normally**                          |
| July 31               | Beta data for L1 Radiometer and Radar released to DAACs                  |
| September 2           | NASA official announcement that all efforts to restart the radar are unsuccessful |
| September 9           | Beta data for L2/3 Soil Moisture Passive (radiometer) released to DAAC    |
| Early November        | Validated data for L1 Radiometer and Radar will be released              |
| Early November        | Beta data for L2/3 Soil Moisture Active/Passive, L4 Soil Moisture and L4  
                         | Carbon will be released                                                  |
| Through April 2018    | Science data available through data centers will be used to demonstrate SMAP  
                         | applications                                                             |
| (nominal mission)     |                                                                           |
Radar Level 1C Product

[Data available April 13-July 7, 2015]

- Each granule contains geographically ordered data in 1 km grid cells in an along track/cross track swath grid.
- Coverage is restricted to land and coastal water over one spacecraft half orbit.
- SAR provides high-resolution single-look measurements. Resolution varies from ~400 m at the swath edge to about 1.2 km at 150 km from the nadir sub-track. Nadir looks are thin slices as wide as the beam footprint.

- Contains Earth located and calibrated h-pol, v-pol and cross-pol backscatter measurements, each separately multilooked.
- Radar measurements achieve 1 km resolution over 70% of the swath. Resolution degrades in the nadir region.
- Forward looking and aft looking measurements stored separately.
- Includes spacecraft orbit and attitude information and instrument pointing geometry.
- Includes short term and external calibration data used to generate product output.
- Provides reference to global and polar 1 km EASE grid coordinates.
Radiometer Level 1B Product

- Each granule contains time ordered data that covers one spacecraft half orbit
- Effective field of view footprint is a 39 km by 47 km ellipse
- Earth-located calibrated data for each EFOV
  - Apparent aperture (antenna) temperatures
  - Top-of-ionosphere (TOI) brightness temperature
  - Surface-referenced brightness temperatures
- Coverage continuous over all surface types.
- All four modified Stokes parameters (V, H, 3 & 4)
  - 3rd Stokes used for Faraday rotation correction
  - Brightness temperature third Stokes is always zero
- Time-frequency-polarization diversity used for RFI detection and removal
- Forward looking and aft looking measurements stored separately
- Includes spacecraft orbit and attitude information and instrument pointing geometry
L2 Radiometer
36 km Soil Moisture Product

- Each granule contains one half orbit of data posted on 36 km cylindrical EASE grid cells
- Data are represented in a one dimensional array
- Product lists only those EASE grid cells within the half orbit swath
- Provides retrieved soil moisture over land with 4% accuracy for low-to-moderately vegetated areas
  - Low to moderate vegetation defined as vegetation water content \( \leq 5 \text{ kg/m}^2 \)
- Applies water body correction and freeze-thaw state detection that were generated with high resolution radar retrievals
- Estimates soil moisture based on AM observations
- Includes quality masks for urban areas, mountainous terrain, dense vegetation, precipitation, snow and ice
L2 Active/Passive
9 km Soil Moisture Product

- Each granule contains one half orbit of data posted on 9 km cylindrical EASE grid cells
- Data are represented in a one dimensional array
- Product lists only those EASE grid cells within the half orbit swath.
- Merges radar and radiometer channels using a time series algorithm and spatial heterogeneity of L1C radar product
- Provides dis-aggregated brightness temperatures at 9 km resolution
- Provides retrieved soil moisture over land with 4% accuracy for low-to-moderately vegetated areas
  - Low to moderate vegetation defined as vegetation water content $\leq 5 \text{ kg/m}^2$
- Employs transient water body and freeze-thaw state generated with high resolution radar retrievals
- Include quality masks for urban areas, mountainous terrain, dense vegetation, precipitation, snow and ice
L4 Surface and Root-Zone Soil Moisture Product

- Global product, presented in two collections
- Based on assimilation of SMAP brightness temperatures from the L1C_TB and L2_SM_AP products into a state-of-the-art land surface model

<table>
<thead>
<tr>
<th>Geophysical Data (&quot;gph&quot; Collection)</th>
<th>Analysis Update Data (&quot;aup&quot; Collection)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-hour time averages</td>
<td>3-hour instantaneous (snapshots)</td>
</tr>
<tr>
<td>Surface and root zone soil moisture, soil temperature, snow, land surface fluxes, surface meteorological forcing data</td>
<td>Brightness temperatures (observed and modeled), soil moisture and soil temperature (model forecast and analysis), uncertainty estimates</td>
</tr>
</tbody>
</table>
L4 Carbon Product

- Daily global maps of net ecosystem CO₂ exchange (NEE) at 9 km resolution with 14-day latency
- Quantifies the net carbon flux in boreal landscapes
- Reduces uncertainty with regard to existing carbon sinks on land
- Applies a soil decomposition algorithm driven by SMAP L4_SM and Gross Primary Production (GPP) inputs to compute net land-atmosphere CO₂ exchange (NEE)
- Accuracy commensurate with tower based CO₂ observations (RMSE ≤ 30 g C m⁻² yr⁻¹ or 1.6 g C m⁻² d⁻¹)
SMAP Resources at the ASF DAAC

The ASF DAAC archives and supports user services for SMAP Radar Level 1 Products

1. ASF SMAP web interface at https://www.asf.alaska.edu/smap

2. ASF Data Access and Distribution
   a. ASF API at https://portal.asf.alaska.edu/get-data/api
   b. Vertex at https://vertex.daac.asf.alaska.edu

3. ASF User Services and Points of Contacts
   a. User Services Representative (uso@asf.alaska.edu)
   b. Project Manager – Scott Arko (saarko@alaska.edu)
   c. Product Owner – Angela R. Allen (arallen@alaska.edu)
SMAP Resources at the NSIDC DAAC

The NSIDC DAAC archives and provides user support for Level 1 Radiometer Products as well as all SMAP Level 2, Level 3 and Level 4 Products

• SMAP Web site
  – http://nsidc.org/data/smap/

• NSIDC Data Search
  – http://nsidc.org/data/search/

• SMAP Data Tools
  – Will be released with data products
  – Subsetting and reformatting on-demand services
  – HDF utilities. Matlab and IDL readers

• User Support
  – http://nsidc.org/forms/contact.html
  – nsidc@nsidc.org
SMAP Website at NSIDC DAAC

Overview

The National Snow and Ice Data Center (NSIDC) and the Alaska Satellite Facility (ASF) will jointly manage SMAP science data on behalf of the NASA ESDIS Project. Currently, NSIDC distributes

Measuring Soil from Space

SMAP is a NASA Earth science mission that uses microwave radar and radiometer instruments to measure soil moisture from space. Read more...

RELATED RESOURCES

SMAP Handbook
Essential information on the programmatic, technological, and scientific aspects of SMAP data and the mission.

SMAP Radar Data at ASF

SMAP Information at NASA
Worldview
EOSDIS Data Visualization, Discovery, and Download Tool for GIBS

- General-purpose, full-resolution satellite imagery browser built to
  - Explore
  - Compare
  - Download
  - Share
  - Educate

- Web browser-based and open source

https://earthdata.nasa.gov/worldview
https://github.com/nasa-gibs/worldview
Soil Moisture Product (36 km) Observed Changes

- Passive data successfully processed into soil moisture
- Soil moisture patterns agree with expected geographical soil moisture distribution
- Soil moisture changes are evident in the time-sequence
- Rainfall in India, Bangladesh, and Vietnam
- Dry-down in eastern Australia and Argentina
Regions where SMAP soil moisture retrievals are expected to meet accuracy requirement of 0.04 m³/m³

Retrieval expected quality mask (black colored pixels) prepared with following specifications:

a) Vegetation water content ≤ 5 kg/m²
b) Urban fraction ≤ 0.25
c) Water fraction ≤ 0.1
d) DEM slope standard deviation ≤ 3 deg
Value of Soil Moisture Data to Weather and Climate

New space-based soil moisture observations and data assimilation modeling can improve forecasts of local storms and seasonal climate anomalies.

Seasonal Climate Predictability

Predictability of seasonal climate is dependent on boundary conditions such as sea surface temperature (SST) and soil moisture – soil moisture is particularly important over continental interiors.

Difference in Summer Rainfall: 1993 (flood) minus 1988 (drought) years

Prediction driven just by SST

Prediction driven by SST and soil moisture

(Schubert et al., 2002)

In weather forecasting, SMAP surface soil moisture, with x10 higher resolution than existing model estimates, will result in enhanced predictions.
A Flood Example

Application of a SMAP-Based Index for Flood Forecasting in Data-Poor Regions

**Current Capability:** The UN-WFP uses satellite derived flood maps to locate floods and map delivery routes to affected areas.

**Enhanced Capability:** Use SMAP to expand their current flood database with look-up information that produces flood indices for a given rainfall forecast (ECMWF) and soil moisture condition (SMAP).

**Study Area:** Zambezi basin and its delta in Mozambique.

**Algorithm Structure:** VIC output on flow is input into a hydrodynamic model (LISFLOOD-FP), which is complemented with a sub-grid channel formulation to generate flood inundation variables (inundated area, floodplain water volume) for the lower Zambezi basin. ECMWF archived forecast rainfall data is used to compute flows for daily inundation patterns over 10 years.

Courtesy of
Guy Schumann
UCLA
A Flood Example: Results

Long-term variations in upstream rainfall and soil moisture column vs. floodplain inundation volume (top left panel) and downstream top layer soil moisture (top right panel). Upstream rainfall plus soil moisture 0.88 and rainfall only 0.49. Downstream top layer soil moisture 0.52. The map depicts long-term variations in floodplain inundation patterns from the LISFLOOD-FP flood model. Regression model results for predicting floodplain inundation volume are shown in the bottom left scatter plot.

These variables were used to regress and predict floodplain inundation volume for the February 2007 flood event, which was taken out when regressing. The regression model had a relative bias of 17%, with a relative error in predicting the 2007 event of 33%.

Courtesy of Guy Schumann, UCLA
Agricultural models have been developed to predict the yield of various crops at field and regional scales. One key input of the agricultural models is soil moisture. The conceptual diagram relates variation in regional domain-averaged soil moisture to variation in total crop yield. Statistical analysis would lead to the development of probability distributions of crop yield as a transformation of the probability distribution of domain averaged soil moisture at the beginning of the growing season.
SMAP for Agricultural Crop Yield and Food Security Applications

Statement of Problem: The world faces an uphill struggle in feeding a projected nine to ten billion people by 2050.

Water is the defining link between the climate and agriculture. To improve agricultural drought decision support systems and ensure food security, better quality and better use of Soil Moisture/Water information is vital.

This information will increase the lead time and skill of crop yield forecasts.

Courtesy of Narendra Das, JPL

Crop Simulation Model for Maize Yield Prediction. RSE-D-12-008/2R2: Remote Sensing of Environment, In Press
A primary goal of NASA’s SMAP Mission is to engage applications end users and build broad support for SMAP applications through a transparent and inclusive process.

Toward that goal, the SMAP Mission:

1. Formed the SMAP Applications Working Group (200+ members)
2. Supports a SMAP Applications Coordinator
3. Developed the SMAP Applications Plan (right)
4. Developed the “Early-Adopter” Program (50+ Members)
5. Holds SMAP Applications Workshops at user agencies and institutions (e.g., NOAA, USDA, USGS)
6. Conducts hands-on tutorials and workshops
## SMAP Applications Early Adopters

<table>
<thead>
<tr>
<th>Early Adopter PI and institution</th>
<th>SMAPI Contact</th>
<th>Weather and Climate Forecasting</th>
<th>Applied Research Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Stephane Belair, Meteorological Research Division, Environment Canada (EC); SMAPI Contact: Stephane Belair</em></td>
<td></td>
<td>Assimilation and impact evaluation of observations from the SMAPI mission in Environment Canada’s Environmental Prediction Systems</td>
<td></td>
</tr>
<tr>
<td><em>Lars Isaksen and Patricia de Rosnay, European Centre for Medium-Range Weather Forecasts (ECMWF); SMAPI Contact: Eni Njoku</em></td>
<td></td>
<td>Monitoring SMAPI soil moisture and brightness temperature at ECMWF</td>
<td></td>
</tr>
<tr>
<td><em>Xiwu Zhan, Michael Ek, John Simko and Weizhong Zheng, NOAA National Centers for Environmental Prediction (NCEP), NOAA National Environmental Satellite Data and Information Service (NOAA-NESDIS); SMAPI Contact: Randy Koster</em></td>
<td></td>
<td>Transition of NASA SMAPI research products to NOAA operational numerical weather and seasonal climate predictions and research hydrological forecasts</td>
<td></td>
</tr>
<tr>
<td><em>Michael Ek, Marouane Temimi, Xiwu Zhan and Weizhong Zheng, NOAA National Centers for Environmental Prediction (NCEP), NOAA National Environmental Satellite Data and Information Service (NOAA-NESDIS), City College of New York (CUNY); SMAPI Contact: Chris Derksen</em></td>
<td></td>
<td>Integration of SMAPI freeze/thaw product line into the NOAA NCEP weather forecast models</td>
<td></td>
</tr>
<tr>
<td><em>John Galantowicz, Atmospheric and Environmental Research, Inc. (AER); SMAPI Contact: John Kimball</em></td>
<td></td>
<td>Use of SMAPI-derived inundation and soil moisture estimates in the quantification of biogenic greenhouse gas emissions</td>
<td></td>
</tr>
<tr>
<td>☯Jonathan Case, Clay Blankenship and Bradley Zavodsky, NASA Short-term Prediction Research and Transition (SPoRT) Center; SMAPI Contact: Molly Brown*</td>
<td></td>
<td>Data assimilation of SMAPI observations, and impact on weather forecasts in a coupled simulation environment</td>
<td></td>
</tr>
</tbody>
</table>

### Droughts and Wildfires

<table>
<thead>
<tr>
<th>Early Adopter PI and institution</th>
<th>SMAPI Contact</th>
<th>Applied Research Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Jim Reardon and Gary Curcio, US Forest Service (USFS); SMAPI Contact: Dana Entekhabi</em></td>
<td></td>
<td>The use of SMAPI soil moisture data to assess the wildfire potential of organic soils on the North Carolina Coastal Plain</td>
</tr>
<tr>
<td><em>Chris Funk, Amy McNally and James Verdin, USGS &amp; UC Santa Barbara; SMAPI Contact: Molly Brown</em></td>
<td></td>
<td>Incorporating soil moisture retrievals into the FEWS Land Data Assimilation System (FLDAS)</td>
</tr>
<tr>
<td>☯Brian Wardlow and Mark Svoboda, Center for Advanced Land Management Technologies (CALMIT), National Drought Mitigation Center (NDMC); SMAPI Contact: Narendra Das*</td>
<td></td>
<td>Evaluation of SMAPI soil moisture products for operational drought monitoring: potential impact on the U.S. Drought Monitor (USDM)</td>
</tr>
<tr>
<td>☯Uma Shankar, The University of North Carolina at Chapel Hill – Institute for the Environment; SMAPI Contact: Narendra Das*</td>
<td></td>
<td>Enhancement of a Bottom-up Fire Emissions Inventory Using Earth Observations to Improve Air Quality, Land Management, and Public Health Decision Support</td>
</tr>
</tbody>
</table>

### Floods and Landslides

<table>
<thead>
<tr>
<th>Early Adopter PI and institution</th>
<th>SMAPI Contact</th>
<th>Applied Research Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Fiona Shaw, Willis, Global Analytics; SMAPI Contact: Robert Gurney</em></td>
<td></td>
<td>A risk identification and analysis system for insurance; eQUIP suite of custom catastrophe models, risk rating tools and risk indices for insurance and reinsurance purposes</td>
</tr>
</tbody>
</table>
SMAP Applications Early Adopters Video

http://smap.jpl.nasa.gov/early-adopters/

Thank you for your attention!
Thank You!

Amita Mehta

e-mail: amita.v.mehta@nasa.gov
Extra Slides
TRMM Measurements

**TMI**
- Frequencies: 10.7, 19.4, 21.3, 37, 85.5 GHz
- Swath: 760 km (870* km)
- Resolution: 5 to 45 km (channel-dependent)

**PR+**
- Frequencies: 13.6 GHz
- Swath: 220 km (247* km)
- Resolution: 5 km

* After the orbit was raised in August 2001   +Stopped after October 7, 2014

**Strength**: High pixel resolution, Accurate measurements

**Limitation**: No global, diurnal coverage on daily basis
GPM Measurements

http://pmm.nasa.gov/GPM

GMI Frequencies:
10.6, 18.7, 23.8, 36.5, 89, 166 & 183 GHz

Swath width 885 km

Resolution: 19.4km x 32.2km (10 GHz)
to 4.4km x 7.3km (183 GHz)

Higher spatial resolutions than TMI
High frequencies help measure snow

Ka 35.5 GHz, Swath Width 120 km, Resolution 5.2 km

Ku 13.6 GHZ, Swath Width 245 km, Resolution 5.2 km
# Summary of GPM Level-2 Precipitation Products

*Surface Rainfall Rate in mm/hour

GPM data are available from March 2014 to present

<table>
<thead>
<tr>
<th>Sensor/Product Name</th>
<th>Spatial Resolution and Coverage</th>
<th>Temporal Resolution</th>
<th>Data Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPR Ku-only/ 2A-Ku</td>
<td>5.2 km x 125 m Single Orbit and 16 orbits per day (70°S-70°N)</td>
<td>20-120 minutes</td>
<td>HDF5 and OPenDAP</td>
</tr>
<tr>
<td>DPR Ka-only/2A-Ka</td>
<td></td>
<td>24 hours</td>
<td></td>
</tr>
<tr>
<td>DPR KU &amp; Ka/ 2A-DPR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GMI/2A-GPROF</td>
<td>4 km x 4 km Orbital and 16 orbits per day (70°S-70°N)</td>
<td>2 – 40 hours</td>
<td></td>
</tr>
<tr>
<td>Combined GMI and DPR/2A-CMB</td>
<td>Orbital (70°S-70°N) 5 km x 5 km, Coincident Ku-Ka-GMI footprints</td>
<td>3 – 40 hours</td>
<td></td>
</tr>
</tbody>
</table>

*In addition to surface rainfall rate in mm/hour, vertical precipitation profiles and latent heating are available in these data products
## Summary of GPM Level-3 Precipitation Products

*Surface Rainfall Rate in mm/hour

GPM data are available from March 2014 to present

<table>
<thead>
<tr>
<th>Sensor/Product Name</th>
<th>Spatial Resolution and Coverage</th>
<th>Temporal Resolution</th>
<th>Data Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMERG</td>
<td>0.1°x0.1° (90°S-90°N)</td>
<td>30-minutes (Near Real Time) with 4-hour latency, 12-hour latency and 4-months latency</td>
<td>HDF4, NetCDF, OPenDAP, ASCII, GIF, PNG Images, KML for Google Earth</td>
</tr>
<tr>
<td>3-CMB Combined GMI + DPR rainfall Averages</td>
<td>0.1°x0.1° (70°S-70°N)</td>
<td>Monthly</td>
<td></td>
</tr>
<tr>
<td>3-DPR rainfall Averages</td>
<td>0.25°x0.25° 5.0°x5.0° (67°S-67°N) for Daily (70°S-70°N) for Monthly</td>
<td>Daily and Monthly, Daily and Monthly</td>
<td></td>
</tr>
<tr>
<td>3-GPROF GMI rainfall Averages</td>
<td>0.25°x0.25° (90°S-90°N)</td>
<td>Daily and Monthly</td>
<td></td>
</tr>
</tbody>
</table>

*In addition to surface rainfall rate in mm/hour, vertical precipitation profiles and latent heating are available in these data products.*